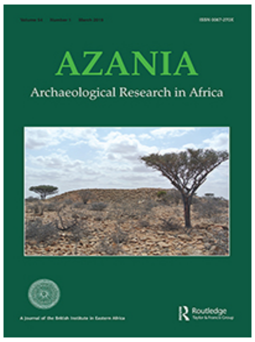

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Fuel selection during long-term ancient iron production in Sudan

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ABSTRACT

The Royal City of Meroe, a capital of the ancient Kushite kingdom in modern Sudan, is renowned for its extensive remains of ancient iron production. The exploitation of wood to fuel Meroe's metallurgical past has long been linked to environmental degradation. However, palaeoenvironmental studies involving archaeobotanical methods such as charcoal analysis, which might confirm or disprove the hypothesis of large-scale deforestation, have so far been missing for the area. Our investigations offer the first comprehensive anthracological data for the iron-smelting contexts at Meroe and its surroundings covering more than 1000 years. They provide unequivocal evidence for extreme selectivity for a single species, the Nile acacia *Acacia nilotica* (Syn. *Vachellia nilotica*), throughout the course of the currently known metallurgical history of the Meroe region. The charcoal data neither point to fuel shortage nor to environmental degradation at any point in time during the entire production period. Non-metallurgical contexts show that a wider array of taxa was used for fuel with low values of *Acacia nilotica* type charcoal. We thus conclude that *Acacia nilotica* wood was preferably used and mainly spared for the technical application of iron smelting. The probable source areas for Nile acacia wood and possible woody resource management strategies to maintain the fuel supply are discussed.

RÉSUMÉ

La Ville Royale de Méroé, capitale de l'ancien royaume de Kush au Soudan, est réputée pour ses énormes restes sidérurgiques. L'exploitation des essences ligneuses pour alimenter les fours de fonte à Méroé a depuis longtemps été mise en rapport avec une forte dégradation environnementale. Cependant, les études paléoenvironnementales mettant en œuvre des analyses archéobotaniques telles que l'anthracologie, qui pourraient confirmer ou réfuter l'hypothèse d'une déforestation à grande échelle, n'avaient jamais été développées dans cette région. Nos recherches apportent, pour la première fois, des données

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anthracologiques provenant de contextes sidérurgiques à Méroé et ses environs et qui s'étendent sur plus de 1000 ans. Ces données démontrent sans équivoque que tout au long de l'histoire métallurgique actuellement documentée dans la région de Méroé il s'est fait une stricte sélection d'une seule espèce, l'acacia à gomme *Acacia nilotica* (Syn. *Vachellia nilotica*). Les données anthracologiques ne révèlent ni des problèmes dans l'approvisionnement en combustible ni une dégradation de l'environnement, et ce tout au long de la période de production. Les contextes non-métallurgiques montrent, quant à eux, une plus grande diversité dans les espèces utilisées comme combustible, avec une faible représentation de charbon de type *Acacia nilotica*. Nous en concluons que le bois de l'*Acacia nilotica* a été utilisé de façon préférentielle et réservé principalement pour l'application technique à la fonte du fer. Nous considérons les zones sources probables pour le bois de l'*Acacia nilotica*, et les stratégies possibles de gestion des ressources ligneuses visant à maintenir l'alimentation en combustible.

Introduction

Archaeometallurgical and archaeobotanical research at Meroe

From the second half of the eighth to the mid-seventh centuries BC, Kushite kings ruled Nubia and Egypt as the Twenty-Fifth Dynasty. By the early third century BC, the capital of Kush had shifted from Napata near the Fourth Cataract of the Nile south to Meroe, from where the kings and queens of Kush ruled until the fourth century AD (for an overview of Kushite history see Welsby 1996; Török 1997, 2015; Edwards 2004). Meroe is particularly famous for its large-scale remains of ancient iron production, which led to the notorious early twentieth-century description of the ancient city that 'Meroë, in fact, must have been the Birmingham of ancient Africa; the smoke of its iron-smelting furnaces must have been continually going up to heaven, and the whole of northern Africa might have been supplied by it with implements of iron' (Sayce 1912: 55).

Archaeometallurgical research at Meroe and the nearby site of Hamadab in Sudan (Figure 1) was relaunched in 2012, leading to the systematic investigation of a number of

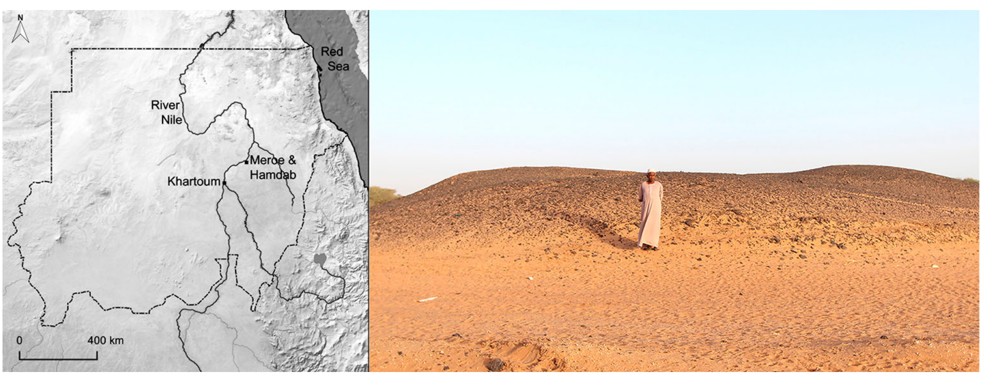

Figure 1. The location of Meroe and Hamadab in Sudan on the east banks of the Nile with (at right) one of the largest slag heaps at Meroe, with site guard Ma'awia Osman Alawad Albasheir providing a scale.

slag heaps across the two sites (Humphris 2014; Humphris and Carey 2016; Humphris and Scheibner 2017; Ting and Humphris 2017). Although already famed as an intensive iron production centre (Trigger 1969; Tylecote 1970, 1982; Shinnie 1985; Rehren 2001), the recent research has provided new insights into the chronology of, and technological approach, to iron production, allowing significant new conclusions to be drawn concerning the role and impact of iron production technology on the broader social, economic and political context of Kush. For example, it is now known that iron production, sometimes on a significant scale, was carried out at Meroe for over 1000 years (Humphris and Scheibner 2017). In order to assess the possible environmental impacts of such a scale and longevity of iron production, a systematic archaeobotanical investigation involving the identification and relative quantification of charcoal taxa was implemented. This research programme has created an analytical database of charcoal exploitation from six slag heaps at the Royal City of Meroe and four slag heaps at the site of Hamadab, dating across the entire period in question from early Napatan to post-Meroitic times. In addition to metallurgical charcoal (i.e.

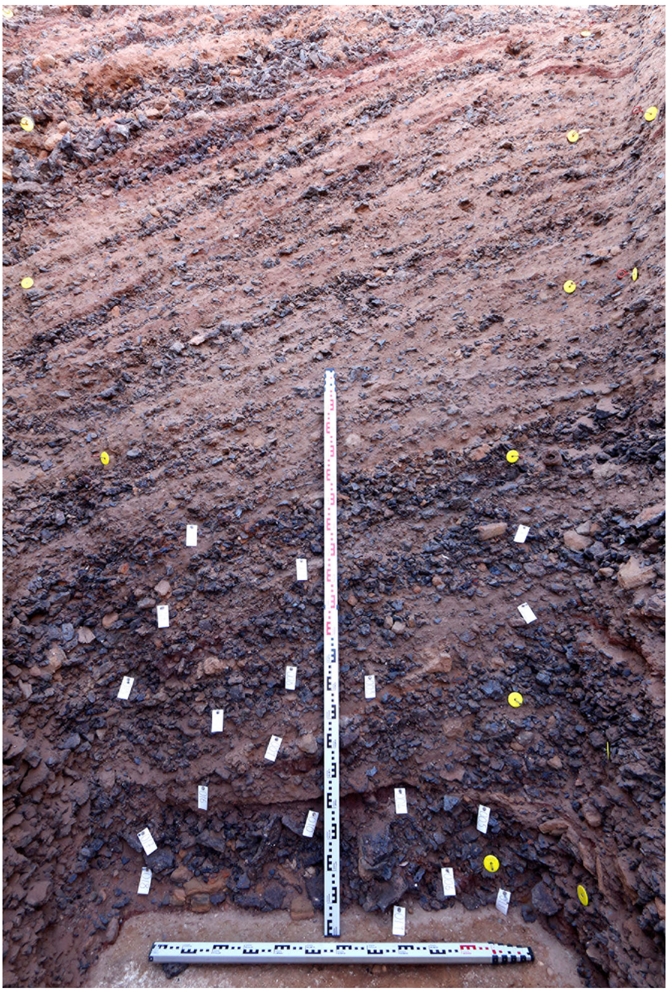

Figure 2. Meroe: MIS 4 Trench 2, west section (2016 season) showing charcoal samples from metallurgical contexts in the lower half of the section undergoing documentation before collection.

Table 1. An overview of the data collected including the site, slag heap, chronology (potential maximum time span of metallurgical production, according to Humphris and Scheibner 2017) and number of charcoal fragments analysed from metallurgical and non-metallurgical contexts.

Site	Slag heap	Attribution to period	Approximate date	Metallurgical charcoal	Non-metallurgical charcoal
Hamadab (HMD)	100	Late and post-Meroitic	Cal. AD 384–560	21	-
Hamadab (HMD)	800	Late and post-Meroitic	Cal. AD 384–553	81	-
Hamadab (HMD)	200	Late and post-Meroitic	Cal. AD 331–552	153	-
Hamadab (HMD)	300	Late and post-Meroitic	Cal. AD 256–532	29	-
Hamadab (HMD)	700	Late and post-Meroitic	Assumed to be the same as above	2	-
Hamadab (HMD)	900	Late and post-Meroitic	Assumed to be the same as above	3	-
Hamadab (HMD)	NA	Meroitic	Meroitic	-	73 (domestic, pottery vessels)
Meroe (MIS)	6	Meroitic, late and post-Meroitic	Cal. AD 179–540	645	-
Meroe (MIS)	1/2	Napatan and Early Meroitic	367–37 cal. BC	32	-
Meroe (MIS)	2	Napatan and Early Meroitic	452–193 cal. BC	29	-
Meroe (MIS)	3	Napatan and Early Meroitic	405–202 cal. BC	414	-
Meroe (MIS)	4	Napatan and Early Meroitic	786–122 cal. BC	252	-
Meroe (MIS)	7	Napatan and Early Meroitic	Napatan and Early Meroitic	13	-
Mining Area (MMA)	Surface slag	Post-Meroitic	Cal. AD 419–539	1	-
Meroe		Meroitic	Meroitic	-	6 (Royal Bath and Apedemek Temple)

Table 2. Total number of metallurgical and non-metallurgical charcoal samples analysed from Meroe and Hamadab.

Site	Metallurgical charcoal	Non-metallurgical charcoal	Total
Meroe	1386	6	1392
Hamadab	289	73	362
Total	1675	79	1754

samples taken directly from metallurgical contexts; Figure 2), charcoal samples collected from non-metallurgical contexts were analysed where possible to generate comparable data. In total, 1754 fragments of charcoal were analysed (Tables 1 and 2).

The potential of charcoal analysis at metallurgical sites

A systematic anthracological investigation at a metallurgical site has the potential to identify the fuel selected for use during ancient iron production processes, thus providing an insight into the relationship between metal producers and their natural environment. It may first of all reveal highly relevant ecological data, such as vegetation change through time that might be due to anthropogenic factors including the over-exploitation of woody taxa for fuel or natural factors such as climate change. Anthracology can also reveal information about the knowledge of those utilising the natural resources available to them (in terms of specific properties of certain vegetation) and how and why ancient landscapes may have changed over time. As Iles (2016: 1220) notes, 'The high volume of charcoal required to smelt metals from ores has meant that for centuries, the development and intensification of metal production has been linked to reductions in forest cover, environmental decline and associated socio-economic change'. Metallurgy is, however, only one of numerous fuel-dependent and wood-consuming ancient activities, which also included undertakings such as ceramic production, cooking and building, to name but a few. Ancient metallurgists, operating with significant fuel requirements, had to learn, adapt and survive within what was sometimes a fragile ecosystem dependent on limited rainfall and access to land, in addition to accommodating the fuel and wood needs of other aspects of society. Negotiating a successful balance within the environmental and societal constraints that ensured that a sufficient fuel supply could be sustained for iron production was presumably essential, especially where large-scale or long-lasting metallurgy was conducted.

Within the study of African iron production, a number of investigations have provided interesting data regarding the ecological impact of the technology and how the craftspeople of the past mitigated their relationship with the natural environment. A notably comprehensive investigation of the fuel choices of iron smelters, for example, is that conducted in the Dogon Country of Mali in West Africa, where systematically collected charcoal remains from the Fiko metallurgical tradition were analysed (Eichhorn 2012; Eichhorn *et al*. 2013a, 2013b). Here, archaeometallurgical and archaeobotanical data were combined in order to test the hypothesis that large-scale iron production of the kind seen in the Fiko Tradition, which produced iron for at least 800 years, would have resulted in significant degradation of vegetation. It was found that fuel choice was not particularly selective in terms of species, with a variety of taxa being exploited, but that it was selective in terms of quality. In this case, the majority of identified taxa represent sources of high-density woods considered most suitable for iron smelting. Vegetation change, including the decrease of certain species and the increase of others, probably linked to high-intensity levels of iron production over a long period of production, was identified. However, large-scale deforestation was not. This study highlights the opposite situation at Kema, another site complex of the same metallurgical tradition, where vegetation change was less evident within the charcoal assemblages under investigation because the individual smelting sites shifted location several times. The local impact on woody vegetation was thus less severe. Only restricted impact on the woody vegetation was also concluded for the Bassar region, situated further to the south in Togo. Here, higher levels of mean annual precipitation allow for higher annual woody biomass reproduction values compared to Mali's more arid Dogon Country (Eichhorn and Robion-Brunner 2017).

Specific yet particularly variable wood species selection for fuel was noted in ironworking societies in Tanzania, where Lyaya (2013) identified sociocultural factors important in determining which types of charcoal were used in furnaces and smithing hearths. Based on an ethnographic investigation involving interviews with community members who remembered past iron production practices, Lyaya lists 61 tree species used in the iron smelting process, four used in the refining process and 53 used during smithing. Interviews revealed an inclination towards the selection of charcoal best suited to the required processes for reasons including giving a 'very strong fire', the ability to 'collect all iron together' and providing a 'very long lasting fire'. Sociocultural factors were also revealed as influencing the choices of the ironworkers when selecting wood species for use as charcoal. Thus, species associated with curing illness and assisting fertility and pregnancy are noted as important to the ironworkers. In this case, Lyaya did not consider environmental degradation in the form of deforestation a by-product of iron production. Rather, he suggests that due to conscious species selection by the ironworkers, fuel exploitation for metallurgy would not have affected the entire standing stock of woody plants.

Further south, anthracological analyses enabled Chikumbirike (2014) to reveal that 30 different tree species were burnt at Great Zimbabwe, indicating the multi-purpose nature of settlement wood use there, whereas only 14 species were exploited at the iron metallurgical site of Chigaramboni in Great Zimbabwe's hinterland. In this investigation, no signs of distinct vegetation change were observed when comparing the modern vegetation of the research area with the charcoal record data, although the disappearance of one *Acacia* species was potentially linked with over-exploitation for fuel. Thompson and Young (1999) explored examples displaying heterogeneity in fuel selection, for example in Iron Age furnaces excavated in Rwanda and Burundi, where over 50 types of fuel were sourced from a range of ecozones, and from the site of Munsa in southwest Uganda where six types of wood charcoal were found associated with a single furnace. They also describe, however, several ethnographic examples from areas of Tanzania, Malawi and along the Kenyan coast where only one particular type of wood was used to produce fuel (Thompson and Young 1999: 223–234).

The investigations outlined above demonstrate the significant potential that archaeobotanical research has for gleaning information about the relationship between iron producers and their natural environments. From this foundation, a comprehensive investigation of the charcoal fuel used for the long-term and, at times, mass production of iron at Meroe associated with the kingdom of Kush has recently been completed.[1] Previously, Kushite iron production has been connected with ecological deterioration due to supposed deforestation resulting from the large quantities of iron production activities evidenced by Meroe's archaeometallurgical remains (Arkell 1961: 167; Haaland 1985; and for more general discussion of iron production at the site see Tylecote 1970; Shinnie and Kense 1982; Shinnie 1985; Humphris and Rehren 2014). However, until now this hypothesis — which implies vegetation change — has not been tested through palaeoecological or archaeobotanical investigations such as pollen or wood charcoal analysis.

In this context, our anthracological investigations at Meroe, one of the capitals of the kingdom of Kush and its royal seat between *c.* 300 BC and AD 350, and the nearby Meroitic town of Hamadab,[2] aimed to:

a) identify the taxa used as fuel for iron smelting;
b) understand the level of consciousness in fuel choice. Fuel choice may have been selective or non-selective. Selective use should be expressed by the dominance of a single or a restricted number of taxa in the charcoal assemblages;
c) provide explanations in the case that selective fuel choice is evident. A particular species may have been selected for various reasons, such as the combustion properties of the wood or wood charcoal (e.g. calorific value, long-lasting and consistent glow). Local availability and secure reproduction of the fuel source, for example

through the preferential use of taxa able to resprout, may also be of major importance;

d) compare the metallurgical charcoal assemblages with charcoal found in settlement contexts to identify whether certain taxa were spared for the technological process of iron smelting; and

e) draw conclusions regarding the possible ecological consequences of Kushite iron-working (e.g. general deforestation, changes in species composition due to the over-use of certain preferred species, or indirect support of species that are able to survive cutting through resprouting from the base or suckers).

Investigating ancient iron production in Sudan

The archaeological context

As illustrated in Table 1 and described in Humphris and Scheibner (2017), iron production took place at Meroe for over one thousand years, and potentially for up to one and a half millennia, making this one of the longest lasting continual iron production locations on the African continent (assuming the short hiatus in the chronology generated so far during this research represents the current state of research rather than a pause in iron production). At certain times, the level of iron production at Meroe appears to have been particularly intense (Humphris in press). The slag heaps investigated for this archaeobotanical study vary in size, shape and chronology. The largest slag heaps (MIS (Meroe Iron Slag) 4 and 3, followed by MIS2 and 1/2), date to the

Figure 3. Meroe: MIS 6 Trench 4, south section (2014 season). Metallurgical deposits overlying earlier architecture.

earlier periods, supporting the current theory of very intense iron production during these times. These early slag heaps tend to be comprised of continuous metallurgical waste. Conversely, slag heap MIS6 and the heaps investigated at Hamadab are comparatively thin metallurgical deposits overlying earlier archaeology (Meroitic) and accumulated sand (Figure 3). Ongoing laboratory analysis is slowly providing an insight into the technological approach to the production of iron over time. It appears that the technological approach to smelting (Birch and Humphris forthcoming) and to the production of the technical ceramics (Ting and Humphris 2017) underwent certain changes over time, while the selection of a specific type of iron ore, for example (Humphris *et al.* 2018a), remained relatively constant.

Methods: archaeobotanical sampling and identification

The wood charcoal samples from Meroe and Hamadab were individually collected from the archaeometallurgical and archaeological contexts identified during excavation. Usually, the samples were collected from the trench sections once full documentation (photography, drawing and context documentation) had been completed. In this way the stratigraphic positioning of each charcoal fragment was recorded. In cases where charcoal was observed embedded within *in situ* slag, the slag samples were collected and the charcoal fragments carefully removed with tweezers. Generally, the charcoal fragments collected during the investigation are well preserved and large enough for a secure attribution to wood anatomical types. In rare cases, the charcoal fragments turned out to be 'vitrified', with a glassy appearance that blurred the relevant anatomical characters, rendering identification difficult or impossible.

In the laboratory, the charcoal fragments were split along the three diagnostic planes (transversal, longitudinal-radial and longitudinal-tangential) used in wood anatomy identifications prior to analysis with a Leica Laborlux incident light microscope. Splitting in the longitudinal directions was carried out using a razor blade. Determination followed the criteria of the International Association of Wood Anatomists for relevant wood anatomical characters (Wheeler *et al.* 1989) and was performed using the modern African wood slide reference collection at the Institute of Archaeological Sciences in Frankfurt-am-Main (Department of Pre- and Protohistory, Archaeology and Archaeobotany of Africa), the 'Inside Wood' internet database and wood anatomical as well as anthracological literature (Neumann 1989; Neumann *et al.* 2001; Eichhorn 2004; Gerisch 2004). Photographic documentation was either carried out with a Leica DM 4000 incident light microscope equipped with a motor focus and camera, or with a Hitachi 4500 scanning electron microscope (SEM). The latter was also used for the investigation of minute structures such as pit vesturing and mineral inclusions.

Following Ekblom *et al.* (2014), we used the 'type' concept for charcoal identification, whereby a type represents a morphological or, in the case of wood charcoal, an anatomical category distinguished from others either by one single typical character or a significant combination of characters. A type may therefore include a single or, more often, several species (cf. Punt *et al.* 2003). This attribution to types is necessary because wood anatomy in most cases does not allow for species level identification, but is instead restricted to higher taxonomic levels.

On completion of the analysis we interpreted the occurrence of the wood anatomical types within the charcoal assemblages in terms of the presence of woody species in the research area, and in terms of palaeoecology. We consider below the possibilities of first changes in taxonomic distribution due to anthropogenic influence or climatic change after the abandonment of the sites and then the import of wood for Meroitic iron smelting.

Results

Charcoal analysis: wood anatomical types at Meroe and Hamadab

With regard to wood type identification and related differential diagnosis we restrict ourselves here mainly to an outline of the relevant distinguishing wood anatomical characters of the two dominant wood anatomical types, *Acacia* type *nilotica* and *Acacia* type. In all investigated metallurgical contexts, the most abundant and most steadily occurring wood anatomical type at both Meroe and Hamadab is *Acacia* type *nilotica* (see below). Most species of the genus *Acacia* occurring in North Africa show a distinct predominantly aliform-confluent distribution of the paratracheal axial parenchyma. In contrast, the only exception, Nile acacia *Acacia nilotica* (L.) Willd. ex Delile (Syn. *Vachellia nilotica* (L. P.J.H. Hurter & Mabb.)), is characterised by considerable proportions of vasicentric axial parenchyma (Figure 4a; Neumann 1989; Neumann *et al.* 2001: 287, 300–301; Gerisch 2004: 96–99; see also images of *Acacia nilotica* in the Inside Wood database). We only attributed charcoal fragments with a character combination typical for the acacias in general and a very distinct manifestation of the character ‘axial parenchyma vasicentric’ (IAWA character 89, Wheeler *et al.* 1989) to *Acacia* type *nilotica*, whereas all fragments with a character combination typical for the acacias together with a clear combination of the features ‘axial parenchyma aliform’ and ‘axial parenchyma confluent’ (IAWA characters 80 and 83) were defined as the general *Acacia* type (Figure 4b). In rare cases, wood charcoal fragments originating from the species *Acacia nilotica* with an atypical distribution of axial parenchyma might also be merged into this latter type as fluent transitions may occur (cf. Gerisch 2004: 103). However, this concerns mainly juvenile, immature wood.

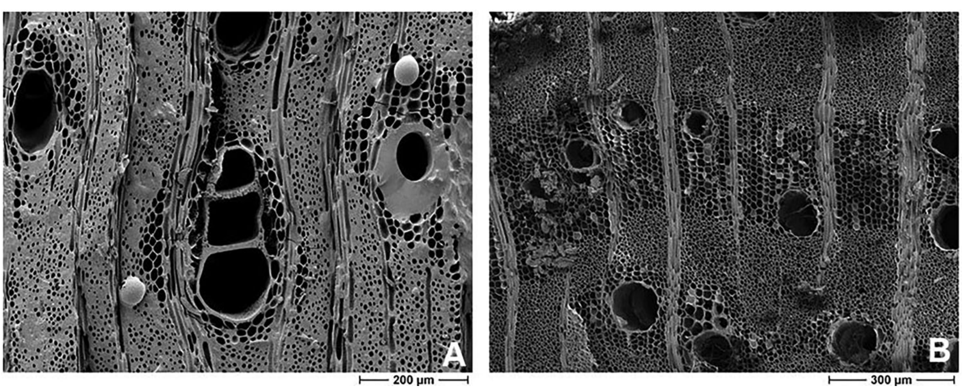

Figure 4. SEM images of wood anatomical types: (a) *Acacia* type *nilotica*, transverse section, vasicentric axial parenchyma; (b) *Acacia* type, transverse section, aliform-confluent parenchyma.

Some of the fragments were only tentatively named cf. *Acacia* type *nilotica*, either because they were too small for an absolutely secure attribution or because anatomical features were blurred due to vitrification. Only a small number of the analysed fragments that are similar to *Acacia nilotica* reference material with respect to axial parenchyma distribution are characterised by low and narrow (one to three cells wide) wood rays and the absence of wider rays. From a wood anatomical perspective, confusion with a small number of other Fabaceae of the subfamilies Mimosoideae and Caesalpinioideae may be possible in these cases, in particular with regards to *Prosopis africana* (Neumann *et al.* 2001: 322). In Sudan, the latter species is at present confined to more humid areas further to the south (El Amin 1990; African Plant Database retrieved August 2017). During Kushite times, woody taxa distribution in the research area might still have been different from today to a certain extent. At the Gala Abu Ahmed fortress in the lower Wadi Howar some 400 km to the west-northwest of Meroe, the charcoal spectrum indicates distinctly higher precipitation than today until at least the turn of the first millennium BC (Jesse *et al.* 2013), post-dating by far the general mid-Holocene desiccation of the Sahara that led to dramatic environmental changes (e.g. Kuper and Kröpelin 2006). By about 700 BC, however, the current hyper-arid ecosystem seems to have been firmly established in the eastern Sahara (Kuper and Kröpelin 2006; Kröpelin *et al.* 2008). Though certainly more thorough research at a regional level within the Nile Valley is required to understand the local palaeoenvironments of Meroe and Hamadab (Wolf 2015: 129), it is rather unlikely that *P. africana* was present in the area during Kushite or post-Meroitic times.

The second most abundant wood anatomical type in all of the metallurgical contexts investigated here is also the most abundant type observed in the charcoal samples from non-metallurgical contexts. This is the general *Acacia* type (Figure 4b) that in the Sahara and the Sahel comprises species of the genus *Acacia* and *Dichrostachys cinerea* (Neumann *et al.* 2001: 287). As with *Prosopis africana*, *D. cinerea* is currently restricted in Sudan to areas to the south of Meroe (El Amin 1990; African plant database retrieved August 2017). A few 'other' taxa are represented in the charcoal assemblages, occurring in higher relative numbers in the samples selected from the non-metallurgical contexts. This category includes cf. *Calotropis procera*, Capparaceae undifferentiated, *Capparis decidua* type, *Leptadenia pyrotechnica, Syzygium* spp., *Tamarix* spp., *Ziziphus* spp., Arecaceae, cf. Arecaceae and monocotyledons/grasses. With the exception of *Syzygium* spp., all of these taxa are still available today in or close to the research area. The *Syzygium* spp. charcoal originates most probably from the species *Syzygium guineense*, which, according to the African Plant Database, 'certainly occurs in a greater range of vegetation types and shows a larger variety of growth forms than any other African plant … ; one of the most widespread African tree species', which has yet been registered in the Sudan only further to the South (African Plant Database retrieved August 2017). The single find in the Hamadab settlement contexts might indicate that this species occurred further north during Meroitic times, most probably extrazonally distributed in the Nile River gallery forest vegetation.

Quantitative results

The quantitative results of the charcoal analyses are presented below as a collective dataset divided between metallurgical and non-metallurgical contexts and also into chronological periods to allow for their contextualisation with regard to the environmental landscape and possible vegetation changes of the Meroe region. Thus, according to Humphris and Scheibner (2017), slag heaps MIS1/2, 2, 3 and 4 are presented as one dataset (referring to the Napatan and early Meroitic periods). MIS6 is first presented alone as a late post-Meroitic production location at Meroe, followed by the data from the metallurgical contexts at Hamadab (a Meroitic town site with metallurgical remains dating to the late and post-Meroitic periods). The charcoal samples from non-metallurgical contexts are presented at the end of the results section.

The complete dataset

Figure 5 illustrates differences in the charcoal assemblages collected from metallurgical and non-metallurgical contexts, presented as overall percentages of charcoal fragment counts for both assemblages. The metallurgical contexts are dominated by a single species of the genus *Acacia*, the Nile acacia, represented by the wood anatomical type *Acacia* type *nilotica*. *Acacia* type, and cf. *Acacia* type *nilotica* are also key categories. Charcoal that could not be classified ('indeterminate') represents 3% of the assemblage, while only 1% of the charcoal examined was categorised as 'other' types of charcoal. The charcoal collected from non-metallurgical contexts is composed of a higher percentage of *Acacia* type charcoal and 'other' types of charcoal. One of the most significant results of this investigation is that *Acacia* type *nilotica* dominates the metallurgical charcoal by almost 90%, but has a significantly lower relative presence within the non-metallurgical context samples.

Napatan and Early Meroitic periods (MIS1/2, 2, 3 and 4)

Acacia type *nilotica* represents 89.9% of the 727 samples collected from metallurgical contexts dating to the Napatan and early Meroitic periods. Of this early assemblage, 4.7%, totalling 34 samples, could not be attributed to a particular type or species, mainly due to their small size. While *Acacia* type and cf. *Acacia* type *nilotica* accounted for 20 samples each (2.8% respectively), none of the samples analysed from these early contexts were identified as 'other' types of charcoal (Figure 6).

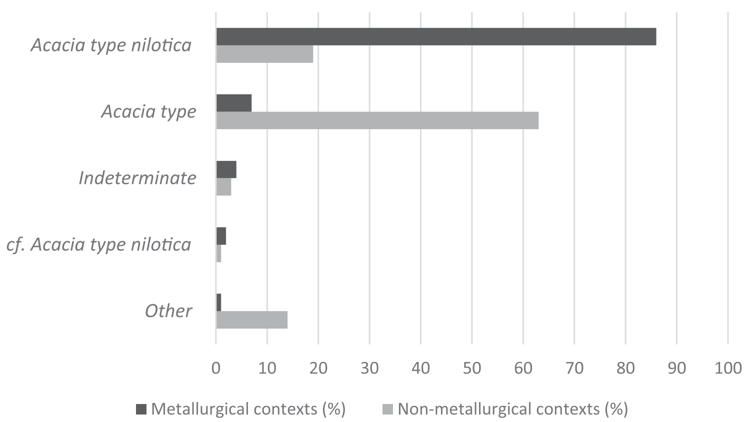

Figure 5. All charcoal types from metallurgical and non-metallurgical contexts presented as total percentages of the assemblage at Meroe (MIS6).

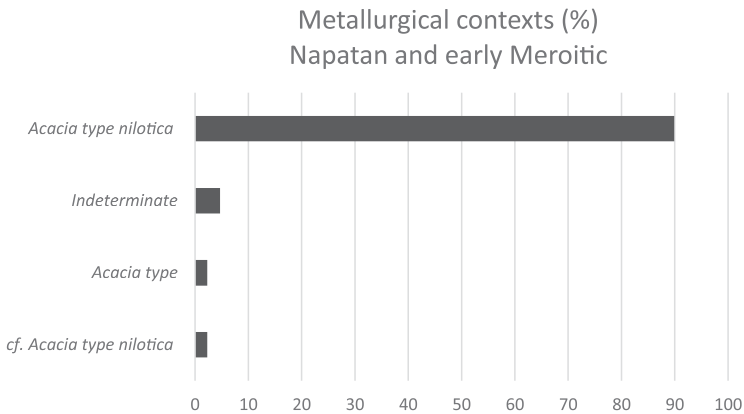

Figure 6. Charcoal types identified within the early charcoal assemblage collected from metallurgical contexts at Meroe (MIS6).

Late and post-Meroitic periods, Meroe (MIS6)

MIS6 was originally the location of the only furnace workshop to have been found during the current research and so warranted a number of seasons of investigation resulting in a higher number of samples collected and analysed (N = 645; Figure 7). This assemblage is also dominated by *Acacia* type *nilotica,* representing 83% (537 fragments). Fragments of *Acacia* type comprise the second largest group, totalling 11%. A further 2% of the assemblage is undeterminable, mostly due to small fragment size, while the same percentage (16 samples) are 'other' types of charcoal. These include four fragments of *Ziziphus* spp., representing spiny shrubs or trees of the genus *Ziziphus* that bear edible fruits and mainly occur on riverbanks and in depressions (El Amin 1990), plus a fragment of *Tamarix* spp. Tamarisks are pioneer shrubs characteristic of the floodplain vegetation in the research area (Wolf *et al.* 2014). Five monocot (grass) samples were collected (four from a single context), while one Capparaceae, one fragment of *Calotropis procera* (shrubs or small trees typical for disturbed areas and village vegetation; El Amin 1990:

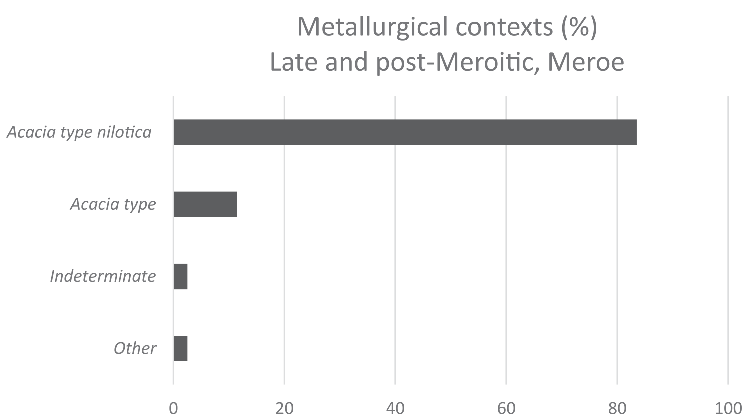

Figure 7. Charcoal types identified within the Meroitic and post-Meroitic charcoal assemblage collected from metallurgical contexts at Meroe (MIS6).

377) and the type *Capparis decidua* were also identified. *C. decidua* is a shrub or small tree typical of desert and semi-desert vegetation, extending on clay soils into low rainfall savannas (El Amin 1990: 31). These 'other' types of charcoal were found in samples from contexts distributed throughout the slag heap and from lower to higher (earlier to later) contexts and may indicate an accidental, or rather non-systematic, inclusion into the charcoal used for iron smelting. The grasses and twigs, particularly of the shrubby plants, may have consciously been used for kindling the charcoal fire in the furnaces.

Late and post-Meroitic periods, Hamadab

As with the charcoal samples analysed from all metallurgical contexts from Meroe, *Acacia* type *nilotica* dominates the assemblage from the metallurgical contexts of Hamadab at a frequency of 85% (Figure 8). As at MIS6, *Acacia* type is the second largest group, here representing 7% of all charcoal fragments. Charcoal classified as cf. *Acacia* type *nilotica* is the next largest group at 4% (N = 11). Only 2% of the charcoal could not be classified, mainly due to its small or fragmented nature, and the same proportion is made up of 'other' types of charcoal, identified also at MIS6, including *Capparis decidua, Tamarix* spp., *Ziziphus* spp, and, in addition, one fragment of charcoal from the semi-desert shrub *Leptadenia pyrotechnica* which is commonly found on the sand dunes of northern and western Sudan (El Amin 1990: 381). Interestingly, these 'other' types of charcoal were only found in the assemblages from HMD 100 and 200 and were not collected from slag heaps 300 or 800. While the Hamadab slag heaps are generally contemporary to each other, their locational separation at the site indicates that they probably represent the waste of different iron production furnaces. Considering that the fragments identified as 'other' types of charcoal presumably represent accidental contamination of an otherwise very selective charcoal assemblage used for smelting, it could be suggested that those responsible for smelting at heaps 300 and 800 were even more selective and careful in their charcoal use. However, due to the small numbers of 'contaminants', and the fact that the charcoal analysed here originates from trenches within the slag heaps rather than from the heaps as a whole, no such conclusion is offered. In the case of *Leptadenia*

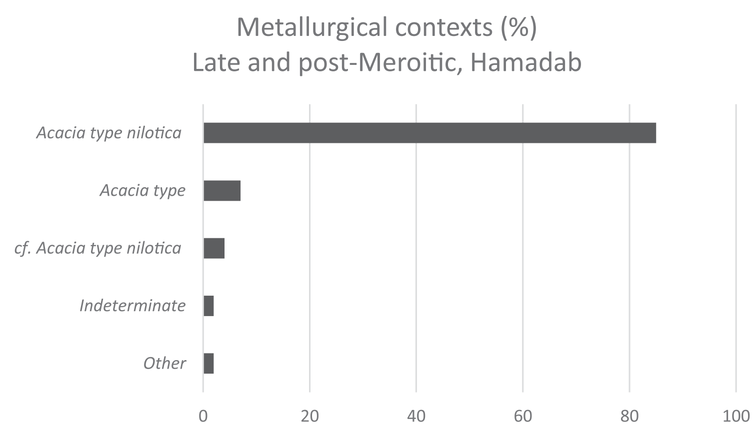

Figure 8. Charcoal types identified within the late Meroitic and post-Meroitic charcoal assemblage collected from metallurgical contexts at Hamadab.

pyrotechnica in particular, an explanation for its presence could relate to the use of this species as kindling (Burkill 1985: 232), i.e. it entered the slag heaps having been used to start the furnace fires.

Additional post-Meroitic metallurgical details.

During the experimental iron smelting campaigns that form a major research avenue of the current archaeometallurgical investigations (Charlton and Humphris 2017; Humphris *et al.* 2018b), a mining location was identified in the hills approximately 9 km to the east of Meroe. During intensive systematic survey of the mining landscape, a number of slag fragments were recovered, within one of which was a charcoal sample. Prior to radiocarbon dating of the fragment, anthracological analysis was performed. The charcoal sample was found to be *Acacia* type *nilotica* and yielded a post-Meroitic date (Humphris *et al.* 2018a). This single sample could indicate that even when testing ores some distance away from the main iron production locations within a particularly vegetation-free, rocky region the smelters still transported and used their preferred type of charcoal for these smelting operations.

Non-metallurgical contexts: early Meroe

Five samples of charcoal collected during the excavation of the Apedemak Temple, situated on top of slag heap MIS3, were analysed, along with one sample collected from Meroe's Royal Baths and provided for this study by Dr Hans-Ullrich Onasch of the German Archaeological Institute. All the samples can be assumed to date to the Meroitic period and relate to the architecture or use of these Meroitic buildings. Three of those from the Apedemak Temple were characterised as cf. Arecaceae (i.e. probably palm), possibly originating from roofing materials or having had a decorative or ritual use within the temple. *Ficus* sp. (fig tree) and grass comprised the other charcoal samples from the Apedemak Temple. The sample from the Royal Baths proved to be palm stem charcoal as evidenced by the presence of palm stem fibrovascular bundles (cf. Thomas 2013) and globular echinate phytoliths (Figure 9). It presumably originates from a structural element of the Baths.

Considering the small sample size available during this investigation, conclusions relating to metallurgical and non-metallurgical charcoal selection are problematic. However, a

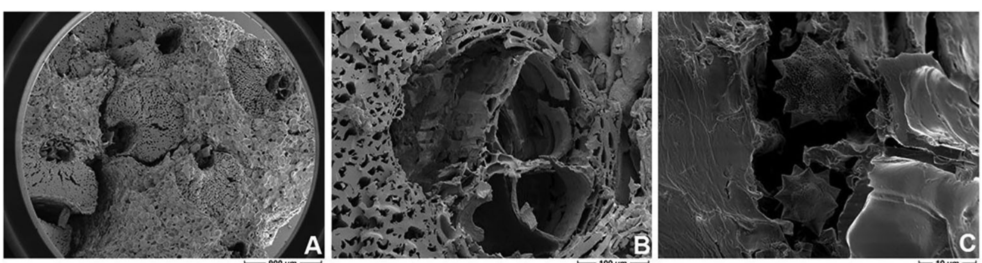

Figure 9. SEM images of wood anatomical types. Arecaceae (a) transverse view, fibrovascular stem bundles embedded in parenchyma matrix; (b) same, detail; (c) longitudinal view: globular echinate phytoliths.

generally more variable assemblage is indicated. These fragments (and especially the grass) were probably not deliberately used as charcoal and therefore this variability more likely reflects the use of plant materials within the temple. Of note despite the small sample size is that *Acacia* is not represented at all.

Non-metallurgical contexts: Meroitic Hamadab

Twenty-nine charcoal samples from the Hamadab Meroitic town excavations were provided by P. Wolf for comparison with the metallurgical charcoal, although we recognise that the metallurgical charcoal largely dates to the late and post-Meroitic periods (see Humphris 2014 and Humphris and Rehren 2014 for additional summaries of these results). An additional 44 charcoal samples collected from within two pottery vessels excavated at Hamadab were also provided. Interestingly, the samples from one of the pottery vessels contained only *Acacia* type charcoal, while those from the second pottery vessel contained 37% (or 13 out of 22 samples) *Acacia* type *nilotica, w*ith the rest of the samples from this vessel being of *Acacia* type. These data demonstrate that *Acacia* type *nilotica,* although not a dominant species for domestic use, was still available for certain non-metallurgical charcoal needs despite its exploitation for iron production. *Acacia* type and cf. *Acacia* type comprises over 50% of the total Hamadab non-metallurgical assemblage and a diversity of other species (including *Ziziphus* spp., *Syzygium* spp., cf. Capparaceae and palm charcoal) are also present.

Discussion

The most significant result of this investigation is that the iron producers of Meroe and Hamadab continually and specifically selected *Acacia* type *nilotica* charcoal for use during iron production, with this species representing 86% of the entire assemblage. If the charcoal samples defined as cf. *Acacia* type *nilotica* are combined with the samples definitively characterised as *Acacia* type *nilotica*, this figure increases to 88%. *Acacia* type accounts for 7%, with other species making up only 1% of the metallurgical charcoal. The (limited) analysis of samples from two Meroitic buildings at Meroe and from the non-metallurgical contexts at Hamadab, support the conclusion that for over 1000 years, throughout the social, economic and political evolution of the kingdom of Kush and despite various changes in technological approach to the iron smelting technology, iron producers continually and specifically selected this one type of wood charcoal.

Why Acacia nilotica?

In order to produce iron successfully using the bloomery method, fuel is required to ensure that the furnace reaches high enough temperatures and to produce a reducing atmosphere able to facilitate the reduction of the iron contained within the ore to iron metal. Thus, almost pure carbon in the form of calorific charcoal fuel is usually used throughout the iron production processes (i.e. for fire-setting, ore roasting, smelting and smithing) as opposed to other types of fuels such as animal dung, uncharred wood and grasses. Charcoal production for metallurgy requires a significant amount of wood and for this reason, as discussed above, iron production is often linked to environmental degradation

(Thompson and Young 1999; Iles 2016). Considering the data presented here in combination with the scale of iron smelting that took place at both Meroe and Hamadab, environmental degradation could potentially have been a result of such activities. However, our evidence shows that a supply of a single type of charcoal was maintained, in large quantities and over a long period of time, without any indication of shortage. Why and how the smelters achieved this continued supply are important questions to consider.

Wood charcoal from *Acacia nilotica* is a perfect fuel choice for iron producers. Structurally stable, it provides a good platform inside the furnace, within and on top of which the smelt can occur. Moreover, its very dense wood has a high calorific value (density 0.65-0.83 g/cm^3, Carsan *et al.* 2012; calorific value: 4800–4950 kcal/kg, National Academy of Sciences 1980). According to Corradi Pereira *et al.* (2012) the use of very dense wood for charcoal production results in the higher production of charcoal for a certain volume of wood and the charcoal quality is improved for various purposes, such as the production of pig iron and steel. Furthermore, *A. nilotica* wood contains abundant calcium oxalate crystals, something that has been suggested to have a distinct influence on the fire-retardant properties of a wood, promoting a slow combustion similar to coal (Prior and Cutler 1992; Gourlay and Grime 1994).

Numerous archaeobotanical finds of *A. nilotica* charcoal indicate its prehistoric importance as fuel in North Africa and beyond. Its use as firewood in the present Eastern Sahara has been documented by charcoal finds dating to as early as 7600–7400 BP at Nabta Playa (Barakat 1996) and 5700 BP at Laquiya/Wadi Shaw (Neumann 1989). Finds at Neolithic Kadero (Central Sudan), currently situated in a semi-desert environment, also date to the sixth millennium BP (Barakat 1995). *Acacia nilotica* charcoal finds from Upper Egypt dating to the fourth and third millennia BC (Vermeersch *et al.* 1992; Newton 2005), the Indus Valley during the Mature Harappan Phase (Lancelotti and Madella 2011), the Egyptian city of Amarna — where it was particularly dominant during Pharaonic times and still present in lower amounts in the Byzantine Period (Gerisch 2004: 285) — the Eastern Desert of Egypt during Roman times — where it has been considered to have been imported from the Nile Valley and appears regularly in artisanal contexts (Bouchaud *et al.* 2018) — and second-millennium AD West African settlement mounds and iron smelting sites (Neumann *et al.* 1998; Eichhorn 2012: Table 1) all provide significant evidence for the continuous and widespread importance of this species as fuel.

An interesting parallel confirming the appreciation of *Acacia nilotica* as a fuel source particularly used for technical applications comes from Amarna, where it was the overall dominant taxon found at sites used to manufacture vitreous materials where it amounted to 95% of all analysed charcoal fragments. In associated non-ferrous slags, *A. nilotica* charcoal was exclusively present. In contrast, fuelwood species composition from household contexts was distinctly more diverse (Zakrzewski *et al.* 2016: 311–312). This pattern resembles our own results, indicating that *A. nilotica* was considered the best fuel for technological production practices.

Acacia nilotica is a fast-growing species (Fagg and Mugedo 2005) that withstands both inundation and extreme temperatures (National Academy of Sciences 1980). Its vigorous growth abilities are expressed by the fact that it is a pioneer species, which can become a weed when introduced out of its native range (Kew Science POWO 2017). Its fast growth makes it a reliable and quickly regenerating fuel source.

According to El Amin (1990: 160), four subspecies of the Nile acacia occur in the Sudan. *A. nilotica* ssp. *nilotica,* and *A. nilotica* ssp. *tomentosa,* are widely distributed along the Nile banks and its tributaries and able to withstand inundations of three or even more months. *A. nilotica* ssp. *adstringens*, on the other hand, grows on light alluvial soils in valleys and on the banks of seasonal rivers, while *A. nilotica* ssp. *subulata* does not occur in the research area but only in South Sudan. A survey of present-day ecology and land use in the Meroe-Hamadab region carried out by Arnaud Malterer has shown that riverbanks there are characterised by lush woody vegetation dominated by *Acacia nilotica* and few other tree species indicating the maximum flood level (Wolf *et al.* 2014: 115). '*Acacia nilotica* woods' are the vegetation unit of the Nile River Valley in the Meroe/Hamadab area, still extending to the Royal City today (Wolf *et al.* 2014).

We can thus state with certainty that *Acacia nilotica* thrived abundantly in the environments of the Meroe area, which, from the early first millennium BC, were flourishing compared to those of other locations: 'After the beginning of the last millennium BC, while decreasing Nile levels and the advancing aridification gradually impeded life and the subsistence of a larger population in the north, the Meroe region, in turn, may have developed into an ecologically favourable region with the geomorphology of its floodplain and its seasonal streams favouring its economic and political development' (Wolf 2015: 130). As a result, the environmental, ecological and climatic landscape was favourable (not just in the Meroe region but also farther afield along the Nile to the north and south, as well as along surrounding the wadi systems) and the species itself was ideally suited to grow in this environment. However, without appropriate human interaction, would it have been driven to extinction considering the quantities of fuel necessary to power the furnaces operated in and around Meroe?

Two other qualities of *Acacia nilotica* may have enabled this species to flourish and thereby have ensured a well-maintained level of charcoal for iron production. The first is the ability of the tree to withstand coppicing, a wood management system involving the felling of trees to almost ground level, following which they regenerate. *Acacia nilotica* can indeed withstand coppicing as well as pollarding (National Academy of Sciences 1980; Gessesse *et al.* 2015). The second important feature to note is indicated by one of the species' common modern names, the 'gum Arabic tree'. The sap from this tree has been used since ancient times as a binder and for medicinal purposes. It was therefore not only the production of the best type of charcoal that could have encouraged the people of the region to carefully manage the supply, but also the tree's economic value as a provider of gum Arabic. A number of other uses are also documented, further indicating its value for multiple purposes, particularly as a valuable source of tannin for tanning leather, medicine, fodder and decoration (in flower garlands) (Gerisch 2004: 99).

It should be noted, however, that the possibility that charcoal was imported to the Meroe furnaces from elsewhere cannot currently be disproved. Trade in charcoal, transported along the Nile, may also be the reason for this maintained supply. New research pursuing investigations into the potential sources of the wood used to make the charcoal for iron production is currently being conducted by Hannah Herrick of the University of Arizona.

From a technological point of view, other woody taxa are also well suited for iron metallurgy. As described in our introduction, other metallurgical traditions in Africa used a wide variety of woody species for iron smelting. Availability (based on favourable growing conditions and accelerated tree growth, as well as the possibility of successful management strategies such as coppicing) combined with high fuel quality, are the most striking arguments for the dominant selection and use of *Acacia nilotica* by the iron producers.

There are, however, other less obvious but imaginable reasons for the almost exclusive use of a single tree species for iron production fuel. Conservative behavioural patterns or religious restraints and belief systems may have played an important role. Such factors are so far unidentifiable in the archaeometallurgical record of the Meroe region, but Haaland (2013) has emphasised the potential significance of iron objects for Meroe's ruling élite. It is conceivable that at certain times, the iron products, and also the production processes including wood exploitation for fuel, were centrally controlled and standardised; these are research questions that we are currently considering as part of our ongoing archaeometallurgical investigations. Such a tradition of wood selection may have later simply continued because the smelters *believed* that the Nile acacia was the only fuel that allowed successful iron production.

How much charcoal?

The quantity of charcoal used during iron production in the Meroe region is as yet unknown and likely changed over time in relation to changing intensity of production and technological style. Recent experimental work (Charlton and Humphris 2017; Humphris *et al.* 2018b) suggests that between 30 and 90 kg of charcoal could have potentially been required for a single smelt, with additional charcoal needed for ore roasting and smithing. Further experiments are being conducted to test such aspects of the technology as fuel requirements. It can certainly be assumed that the requirements of charcoal for iron production per year were significant.

Conclusions

This investigation has demonstrated extreme selection of a single species of wood charcoal throughout the course of the currently known metallurgical history of the Meroe region. Assuming that this fuel was sourced locally, the charcoal data provide no evidence for environmental degradation. Perhaps the woodlands were managed carefully, perhaps the scale of production over time was much lower than currently imagined or perhaps an approach to smelting was used that was particularly fuel-efficient. Alternatively, fuel could have been imported.

Based on the other species found within the assemblage, it would seem that the landscape of ancient Meroe may have been more forested (perhaps not only due to a favourable environment but also to woodland management strategies that may be indicated by the apparent abundance of small branches and twigs in the assemblages) and that it was similar in diversity as today. A generally low biodiversity would help well-established species to thrive. Thus, palm would be found along the Nile, while the wooded areas would contain more shrubs and trees. The crops so essential to the success of Kush would have been grown on the banks of the Nile, and the wadi systems would have provided additional, localised environments for plant life to flourish further from the river (Wolf 2015). Of course, the extent of access to woodland, and how far exchange networks for charcoal existed, is currently unknown. Meroitic sites further to the south such as

El-Hassa, Muweis and Wad ban Naga, also on the Nile, as well as the regional wadi systems, could have contributed to Meroe's charcoal supply in exchange for goods or as a form of tribute. Recent palaeoenvironmental research by Wolf and his team may well shed further light on the wider landscape use of the Kushite period in due course.

An interesting avenue for future investigation would be a systematic consideration of the charcoal used in other pyrotechnologies, such as ceramic and lime production, and further comprehensive archaeobotanical studies at other Meroitic sites. Such work would enable the view of the interaction between people and their environment proposed here to be understood in much greater detail.

Notes

1. The anthracological research presented here was funded largely by a grant from the British Institute in Eastern Africa, and took place while the project was based at UCL Qatar.
2. Archaeometallurgical research at Hamadab is made possible through a co-operation agreement with Dr Pawel Wolf, German Archaeological Institute.

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Barbara Eichhorn studied biology at Goethe University in Frankfurt-am-Main where she completed her diploma degree with a thesis on field weed phytosociology in southern Burkina Faso. She holds a PhD in Natural Sciences from the University of Cologne. Her thesis focused on wood charcoal analysis and the late Quaternary vegetation history of northwestern Namibia. Since then, her research has mainly been dedicated to archaeobotanical macroremain, charcoal and phytolith studies at African sites, focusing on the impact of climate and humans on Holocene vegetation and landscapes.

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